Analysis of Surface Roughness, Fracture Toughness, and Weibull Characteristics of Different Framework-Veneer Dental Ceramic Assemblies after Grinding, Polishing, and Glazing

Pradíes, Guillermo ; Godoy-Ruiz, Laura ; Özcan, Mutlu ; Moreno-Hay, Isabel ; Martínez-Rus, Francisco

Abstract: PURPOSE To compare the surface roughness and biaxial flexural strength of dental ceramics obtained after chairside surface modification by mechanical polishing procedures, versus laboratory reglazing. MATERIALS AND METHODS Discs ($16 \times 1.5 \pm 1.6$ mm) (N = 90) of various framework-veneering combinations were fabricated: D/FC: lithium disilicate/feldspathic ceramic; Z/AL: zirconium dioxide/aluminous ceramic; N/FC: noble alloy/feldspathic ceramic; N/FF: noble alloy feldspathic with fluorapatite; B/FC: base alloy/feldspathic ceramic; B/FF: base alloy/feldspathic ceramic with fluorapatite. In each group 10 specimens were ground using a diamond bur (46 m) and five were polished with silicone-reinforced disc polishers (25 m). Surface roughness (Ra) was measured using contact profilometry. After thermocycling in artificial saliva (6000 cycles, 5 to 55 ± 5°C), biaxial flexural strength was measured using "piston-on-three ball" test. The data (N) were analyzed using one-way ANOVA, Bonferroni, and Tukey's posthoc tests. Weibull distribution values were calculated. RESULTS Surface roughness was significantly higher in the ground group only ($p < 0.0001$). Mean fracture toughness was significantly lower for chipping (RK: 287, HS: 22, ISO: 1099 MPa) than for total fracture ($p < 0.05$), (RK: 841, HS:64, ISO: 3222 MPa). For chipping, Weibull distribution presented the highest shape value (m) for D/FC (3.82-5.07) and for total fracture for B/FC (3.69-4.6). CONCLUSION Chairside surface polishing restored veneer ceramic roughness and mechanical strength to the level of glazing. Feldspathic ceramic with fluorapatite presented better polishing results than conventional feldspathic ceramic did. Ceramic fused to metal was more resistant than lithium disilicate or zirconium dioxide framework-veneer assemblies. Lithium disilicate framework veneered with feldspathic ceramic presented more durability against chipping. CLINICAL IMPLICATIONS After chairside occlusal modifications in the surfaces of cemented all-ceramic or fused-to-metal FDPs, mechanical polishing procedures should always be carried out.

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Analysis of the Surface Roughness, Fracture Toughness and Weibull Characteristics of Different Framework/Veneer Dental Ceramic Assemblies After Grinding, Polishing and Glazing

Laura Godoy Ruiz, DDS, PhD,[1] Francisco Martínez Rus, DDS, PhD,[1] Mutlu Özcan, DDS, DMD, PhD,[1] I Moreno, DDS, PhD,[1] Guillermo Pradíes, DDS, PhD[2]

[1]Complutense University of Madrid, Department of Buccofacial Prostheses, Faculty of Dentistry, Madrid, Spain

[2]University of Zurich, Dental Materials Unit, Center for Dental and Oral Medicine, Clinic for Fixed and Removable Prosthodontics and Dental Materials Science, Zurich, Switzerland

Short title: *Influence of grinding, polishing and glazing on ceramic systems*

***Correspondance:**
Prof. Dr. Mutlu Özcan
University of Zurich
Center for Dental and Oral Medicine
Clinic for Fixed and Removable Prosthodontics and Dental Materials Science
Dental Materials Unit
Plattenstrasse 11
CH 8032, Zurich, Switzerland
E-mail: mutluozcan@hotmail.com

Abstract

Purpose: After cementation of fixed dental prosthesis, slight modifications of the occlusal contacts are commonly required in specific areas to eliminate premature contacts with the adjacent or antagonist teeth. This study compared the surface roughness and biaxial flexural strength of dental ceramics after chairside surface modification procedures versus laboratory reglazing.

Materials and Methods: Discs (16x1.5±1.6 mm) (N=90) of various framework-veneering combinations were fabricated: a) D/FC: Lithium disilicate (IPS e.max Press)/Conventional feldspathic ceramic (IPS e.max Ceram), b) Z/AL: Zirconium dioxide (Lava)/Conventional aluminous (Lava Ceram), c) N/FC: Noble alloy (Cerapall)/feldspathic ceramic (IPS InLine), d) N/FF: Noble alloy (Cerapall)/Feldspathic with fluorapatite (IPS d.Sign), e) B/FC: Base alloy (Tilite)/Conventional feldspathic (IPS InLine), f) B/FF: Base alloy (Tilite)/Feldspathic ceramic with fluorapatite (IPS d.Sign). In each group 10 specimens were ground using a fine grit flame shaped diamond bur (46 µm) and five specimens were randomly assigned for polishing with silicone diamond reinforced disc shaped polishers (25 µm). Surface roughness (Ra) of each specimen was measured using contact profilometry. After thermocycling in artificial saliva (6000 cycles, 5 to 55±5ºC), biaxial flexural strength was measured using “piston-on-three ball” test. The data (N) were analyzed using 1-way ANOVA. Weibull distribution values including the Weibull modulus (m), characteristic strength ($_0$), and probability of failure at 5% ($_{0.05}$), 1% ($_{0.01}$), correlation coefficient were calculated.

Results: Surface roughness was the highest in the ground group (P=0.000). No significant differences were found between glazed and polished specimens (p=0.83). The polished specimens showed significantly higher biaxial flexural strength than those of glazed and ground specimens (p=0.003). Weibull distribution presented lower shape value (m) of KE (m=5.48; CI. 3.5-8.6) compared to LC (m=7.68; CI. 5.2-11.3).

Conclusion: Chair side surface polishing procedures could restore the surface roughness of veneer ceramic and mechanical strength to the level of glazing. Ceramic fused to metal groups, and specifically with base alloy, was mechanically more resistant than lithium disilicate or zirconium dioxide framework-veneer assemblies. Feldspathic ceramic with fluorapatite presented better polishing results than conventional feldspathic ceramic.

Keywords

Ceramic, Glaze; Finishing; Fracture toughness, Polishing; Surface roughness.

Introduction

Ceramics today are widely used in most fixed dental prosthesis (FDP) because of their favorable optical properties, durability and biocompatibility.[1] Traditionally, ceramics have been used as veneering material on metallic frameworks that provide the required physical properties. Metals used in prosthetic dentistry are principally gold or palladium based noble alloys and base alloys such as cobalt-chrome or chrome-nickel. Due to higher translucency and thereby better optical properties, the current trend is the use of metal-free, all ceramic systems especially for anterior FDPs. Most of the all-ceramic framework options are heat-pressed or CAD/CAM processed being mainly composed of lithium disilicate or zirconium dioxide. Feldsphatic ceramics are still being used as veneering material due to their high translucency similar to natural teeth.[2]

The bonding between veneering ceramic and metal in porcelain-fused-to-metal FDPs has been extensively studied. The strength of this bonding is due to the formation of an oxide layer, mechanical and compressive-rheological interlocking between both components. However, ceramic-to-ceramic bond is mainly chemical bonding because of the formation of new crystal phases between different ceramic framework and the veneering ceramic. Unfortunately, particularly zirconium dioxide framework-veneer bonding remains to be a clinical problem where the incidence of delamination or chipping has been reported up to 25% after 31 months.[3-5] One of the reasons for such failures was associated with the roughness of the veneering ceramic.[x]

Biomechanical properties and surfaces of materials can be affected by the aggressive oral milieu and the presence of saliva, acidic drinks and plaque which alter the surface roughness of ceramics over time.[6,7] Rough ceramic surfaces could also occur as a result of technical procedures during the workflow of prosthetic work. Several factors may influence the final shape and dimensions of the FDP, such as impression materials, impression techniques and laboratory procedures. Also, cement thickness may yield to premature contacts after cementation of the FDP that needs to be removed using dental burs in order to achieve proper contact with the adjacent or antagonist teeth. Clinically, the grain size of the burs, pressure, speed and duration dictates the roughness of the veneering ceramic. Such intraoral alterations reduces the ceramic thickness, removes the glazed layer, revealing a rougher surface which consequently decreases the fracture toughness of the restoration,[8,9] increases the wear of opposing restoration and/or teeth enamel[10,11] and promotes pigmentation of the ceramic.[6] When premature contacts are eliminated prior to cementation, the FDP could be autoglazed or overglazed in the dental laboratory.[7] However, after cementation, such adjustments needs to be repolished manually. Several studies showed that appropriately polished ceramic surface can be achieved clinically by means of polishing without necessitating glazing afterwards in the laboratory.[12-14] Other studies also reported that smoother surfaces could be obtained with chairside grinding and polishing similar to autoglazed surfaces.[15,16] Nevertheless, fracture toughness of the veneering ceramics could be affected by such procedures depending on the chemistry of the ceramic.

The objectives of this study therefore were to compare the surface roughness and fracture toughness of framework-veneer ceramic assemblies after chairside grinding and polishing procedures versus laboratory glazing techniques. The null hypothesis tested was that polishing and glazing procedures would not affect surface roughness and fracture toughness of different ceramics.

Materials and Methods

Preparation of specimens

Discs shaped specimens (diameter: 16 mm, thickness: 1.5±1.6 mm) (N=90) of various framework-veneering combinations were fabricated after processing wax patterns, investment and casting except for the zirconium dioxide framework for which CAD/CAM processing was used. Specimens were divided into six groups, depending on the combination of materials (Table 1):

Group D/FC: Framework disks were made through lost-wax casting and press technology using a low-fusing lithium disilicate glass-ceramic. Wax pattern was made (K2 exact, Bredent GmbH&Co.KG, City, Germany) and invested (IPS Press VEST, Ivoclar Vivadent, Schaan, Liechtenstein) and finally wax was eliminated in the preheating furnace (KaVo mod. 5522, Biberach, Germany). Manufacturer´s instructions were strictly followed in terms of time and temperature during operating the furnace (Programat EP 600, Ivoclar, Vivadent). After cooling for 60 min at room temperature, frameworks were veneered with the conventional feldespathic ceramic using layering technique, in two layers and fired (ProgramatEP 500, Ivoclar, Vivadent). Finally, specimens were overglazed (IPS e.max Ceram Glaze, Ivoclar, Vivadent) and no mechanical polishing was performed.

Group Z/AL: In this group, framework discs were obtained from presintered partially yttria stabilized zirconia blocks with CAD/CAM technology (Lava CNC 240, 3M ESPE, Seefeld, Germany). Then, highly aluminous feldspathic veneering ceramic was applied employing layering technique and overglazed (Lava, 3M ESPE) following manufacturer´s instructions. No mechanical polishing was realized.

Group N/FC: Noble alloy framework discs were fabricated by lost-wax technique. After wax pattern was made (BEGO Dental GmbH&Co.KG), investment and casting process were carried out (GC Vest Premium, GC, Tokyo, Japan) and finally wax was eliminated in the preheating furnace (KaVo mod. 5522, Biberach, Germany). The alloy was heated at the melting point according to manufacturer´s recommendations for the casting procedures (Ducatro, Ugin Dentaire, Seyssins, France). Specimens were cleaned by airborne particle abrasion and placed in the furnace for oxidation (Programat 500). Then, veneering ceramic was applied by layering technique where two layers of opaque and two layers of dentin ceramic were used. Specimens were then overglazed with a pre-mixed syringe (Ivoclar, Vivadent).

Group N/FF: For this group, the same procedures were followed as decribed for the N/FC group but for veneering feldspathic with fluorapatite ceramic was used where two layers of opaque and two layers of dentin ceramic were used. Specimens were then overglazed with a pre-mixed syringe (Ivoclar, Vivadent).

Group B/FC: In this group, identical fabrication procedures were followed as for N/FC but regarding the manufacturer´s specifications for the base alloy.

Group B/FF: In this group, identical fabrication procedures were followed as for B/FC group for the metal frameworks and veneering was similar as described for N/FF group.

Surface roughness analysis

The specimens were cleaned ultrasonically in distilled water and dried. Surface roughness was measured using contact profilometeter (Perthometer M1, Mahr, Göttingen, Germany) where two roughness parameters, R_a (average roughness value) and R_z (average of five maximum peaks of roughness value), were registered in microns. These measurements were considered as baseline measurements. To rule out the weight loss associated with contact profilometry, specimens were weighed in a digital balance (PCB BSH 1000, Germany) before and after roughness measurements and no weight loss was identified. Then, in each group 10 specimens were subjected to manual grinding using a fine grit flame shaped diamond bur (46 µm) (DZ92, Lot Nº 041105 Drendel+Zweiling, Berlin, Germany) at high speed (450000 rpm) under water-cooling. One operator performed grinding using a new bur for each group and supporting the specimens on a horizontal surface for the duration of 30 s. Surface roughness was measured again considering R_a and R_z parameters. Thereafter, five specimens from each group were manually polished using silicone diamond reinforced (25 µm) disc shaped polishers (OptraFine F, Ivoclar Vivadent) at low speed (135000) under water-cooling. Again, one operator performed polishing using a new polisher for each group under the same conditions as for grinding and surface roughness was measured.

Subsequently, the specimens were thermocycled (pat. nº P201200882 Complutense University of Madrid, Spain) for 6000 cycles between 5±5°C and 55±5°C with dwell time of 20 s in each bath and 3 s immersion in artificial saliva.

Biaxial flexural strength analysis

Biaxial flexural strength was measured by means of “piston-on-three ball” biaxial flexural strength test (Autograph AG-X, Shimadzu, Kyoto, Japan) with the framework facing the piston (Fig. 1). First, fracture toughness values were recorded at the first peak on the stress-strain curve, also called chipping, second, at the veneer fracture (Fig. 3). Biaxial flexural stregth was calculated according to Roark's[17] formula (a), Roark's[17] formula modified by Hsueh et al. [18-20] (b) and ISO 6782 for multilayered materials(c):

$$\delta = \frac{E_2(z-z_n^*)P}{8\pi(1-\nu_2)D^*}\left\{2\ln\left(\frac{a}{b}\right)+\frac{(1-\nu)(a^2-b^2)}{(1+\nu)R^2}\right\} \quad \text{(a)}$$

$$z_n^* = \frac{E_1 t_1^2 / 2(1-\nu_1^2) + E_2 t_2^2 / 2(1-\nu_2^2) + E_2 t_1 t_2 /(1-\nu_2^2)}{E_1 t_1 /(1-\nu_1^2) + E_2 t_2 /(1-\nu_2^2)} \text{ (b)}$$

$$D^* = \frac{E_1 t_1^3}{3(1-\nu_2^2)} + \frac{E_2 t_2^3}{3(1-\nu_2^2)} + \frac{E_2 t_1 t_2 (t_1 + t_2)}{1-\nu_2^2} - \frac{\left[E_1 t_1^2 /\left(2\left(1-\nu_1^2\right)\right) + E_2 t_2^2 / 2(1-\nu_2^2) + E_2 t_1 t_2 /(1-\nu_2^2)\right]^2}{E_1 t_1 /(1-\nu_1^2) + E_2 t_2 /(1-\nu_2^2)} \text{ (c)}$$

$$\nu = \frac{\nu_1 t_1 + \nu_2 t_2}{t_1 + t_2}$$

where, *P* is stress in Newtons, t_1 or t_a is the veneering ceramic thickness in mm, t_2 or t_b is the framework thickness in mm, *a* is the radius of the supporting area, *b* is the radius of the loaded area in mm, *r* is the radius of the specimen in mm, $\surd_1$ or $\surd_a$ is the Poisson ratio of the veneering ceramic, $\surd_2$ or $\surd_b$ is the Poisson ratio of the framework material, $\surd_e$ is the equivalent Poisson ratio, E_1 or E_a is the elastic modulus of veneering ceramic, E_2 or E_b is the elastic modulus of framework material.

Statistical analysis

Statistical analysis was performed with SPSS Statistics for Windows Version 19 (SPSS, IBM, Armonk, New York, USA). Pearson´s correlation test, Spearman´s Rho and repeated measures analysis of variance were performed between R_a and R_z values. Due to significant difference in groups ($p<0.01$), only R_a values were considered for the analysis. Likewise, three different formulas applied to fracture toughness showed identical results, thus Roark`s formula modified by Hsueh et al. was chosen for the statistical analysis. Data were analyzed using one-way analysis of variance (ANOVA) followed by Bonferroni´s and Tukey´s post hoc tests for multiple comparisons. Weibull distribution values including the Weibull modulus (*m*), characteristic strength ($_0$), probability of failure at 5% ($_{0.05}$), 1% ($_{0.01}$), correlation coefficient were calculated:

$$ln\ ln \frac{1}{1-F_{(\sigma_c)}} = m\ ln\ \sigma_c - m\ ln\ \sigma_0$$

P values less than 0.01 were considered to be statistically significant in all tests.

Results

The repeated measures analysis of variance showed significant differences between the three surface treatments ($F_{(2,58)}$=53.197; p <0.0001). The surface roughness values (Ra) depending on the surface treatment were 1.9±0.5 µm for the glazed, 3.5±0.7 µm for the ground, and 1.7±1.1 µm for the polished specimens. Glazed and polished groups did not show significant difference (p>0.01) being significantly lower than the ground specimens (Bonferroni test) (p<0.0001) (Table 2).

Differences between the combination of material groups with a two-factor analysis of variance (framework-veneer materials) resulted in no statistically significant differences between framework materials ($F_{(2,88)}$=0.049; p=0.826). However, statistically significant differences were found between veneer materials ($F_{(2,88)}$=13.58; p<0.001), specifically between the conventional feldspathic veneer (IPS Inline) and feldspathic with fluorapatite (IPS d.Sign) with lowest Ra values for the latter (Tukey`s).

Three formulas cited above showed high degree of correlation according to Pearson coefficient and Spearman´s Rho (p<0.01). The biaxial flexural strength values at chipping were 25.6±2.55 MPa for glazed, 16.3±7.9 MPa for ground, and 61.6±6.33 MPa for polished group. Biaxial flexural strength values were 37.1±3.01 MPa for glazed, 20.1±1.13 MPa for ground and 101.1±5.57 MPa for polished specimens. Independent samples analysis of variance showed statistically significant differences between the three surface treatments for biaxial flexural strength at both chipping ($F_{(2,86)}$=9.48; p<0.0001) and total veneer fracture ($F_{(2,86)}$=34.72; p<0.0001). Polished specimens after grinding, showed higher values than those of other groups (Fig. 4, Table 3).

The two-factor analysis of variance (surface treatment and materials) showed statistically significant differences between groups for biaxial flexural strength at both chipping ($F_{(5,83)}$=8.42; p<0.0001) and total veneer fracture ($F_{(5,83)}$=7.41; p<0.0001). Veneer ceramic type did not affect biaxial flexural strength at chipping ($F_{(3,85)}$=2.54; p=0.062) but did for total fracture ($F_{(5,83)}$=9.57; p<0.0001). Veneers of all-ceramic specimens were less resistant than metal-ceramic ones (Fig. 5). On the other hand, framework material affected both chipping ($F_{(3,85)}$=12.26; p<0.0001) and biaxial flexural strength ($F_{(5,83)}$=10.1; p<0.0001). Related to chipping, base alloy proved to be the most resistant one than noble alloy (p<0.01) and ceramic framework. Lithium disilicate and zirconium dioxide framework materials did not show significant difference for chipping (p=0.535) and total fracture (p=0.11) but their biaxial flexural strength was significantly less than those of base and noble alloys (p<0.003) (Fig. 6).

Weibull distribution presented lower shape value (*m*) of KE (*m*=5.48; CI. 3.5-8.6) compared to LC (*m*=7.68; CI. 5.2-11.3). Characteristic strengths ($_{0}$) (KE: 1784.9 N; LC: 1712.1 N) were higher than probability of failure at 5% ($_{0.05}$) (KE: 1038.1 N; LC: 1163.4 N) followed by 1% ($_{0.01}$) (KE: 771 N; LC: 941.1 N), with a correlation coefficient of 0.966 for KE and 0.924 for LC (Table 1, Fig. 2).

Discussion

Clinical practice often necessitates the adjustment of ceramics before or even after cementation of FDPs to establish adequate contact with the opposing and/or adjacent teeth. These corrections performed by rotating instruments produce rougher surfaces, promote plaque accumulation,[22] decrease fracture toughness,[,22,23] and increase the wear of the opposing natural teeth as well as restorative surfaces,[10,11] Re-glazing the ground ceramic restorations may increase chair-side time[24] and it is not always feasible as some adjustments can only be made after cementation.[2,8] Thus, it seems necessary to find out whether it is possible to obtain smooth ceramic surfaces similar to glazed surfaces after clinical adjustments. Smooth surfaces would also prevent possible chipping or fracture of the veneering ceramic.

This study was undertaken to compare the surface roughness and biaxial flexural strength of framework-veneer ceramic assemblies after chairside grinding and polishing procedures versus laboratory glazing techniques. Based on the results of obtained, the null hypothesis tested was that polishing and glazing procedures would not affect surface roughness and biaxial flexural strength of different ceramics could be rejected.

The simulated chair-side ceramic grinding with fine grit flame shaped diamond bur resulted in mean roughness value of 3.5±0.72 µm similar to previous studies,[7,25] being significantly higher than glazed surfaces. When ceramic surfaces were polished using silicone diamond reinforced disc shaped polishers, surface roughness values were 1.67±1.08 µm comparable to those of the glazed ones (1.9±0.45 µm). These results are less than those of other reports.[12-14] In this study, only one polishing bur was used to polish the surfaces and no polishing paste was utilized in order to reduce number of steps and materials. Yet, the results were similar to those investigations where polishing kits were used that involved a sequence of discs or polishing pastes.[12-14] Not only the surface coating of the burs but also the duration of the polishing dictates the roughness of the ceramic surface. In this study, this procedure was practiced for 30 s which is less than other studies[23,24] and longer than others.[25-27]

The biaxial flexural strength results should be interpreted with caution. Biaxial flexural strength data for ceramics provided by the manufacturers or ISO 6872 typically concern only monolayer ceramic meaning that framework material is not taken into account. In fact, mechanical properties of the framework-veneer interface play an important role in the mechanical behaviour of the veneer. Similarly, previous studies considered framework materials and veneer ceramic separately when reporting their biaxial flexural strength.[26,27] Furthermore, the Roark`s formula modified by Hsueh et al.[18-20] is not frequently used. Nevertheless, this formula seems to be the most appropriate for testing multilayer ceramics and due to the high correlation observed with Roark´s and ISO 6872 formulas was selected to analyze the results of this study.

Chipping and biaxial flexural strength values (MPa) were 28.6±2.55 and 37.1±3.08 for glazed, 16.27±7.9 and 20.9±1.13 for ground 61.6±6.33 and 101.9±5.57 for polished specimens after grinding, respectively. No differences were found between glazed and ground groups but polished group showed significantly greater values. Based on these results, it can be stated that grinding simulating chairside adjustments do not decrease biaxial flexural strength but polishing after grinding increases the mechanical properties of the tested materials. One explanation for the increased biaxial flexural strength after polishing could be due to the heat generated from surface friction between polisher and ceramic produced during compressive forces. [8,15,28-30] ISO 6782 suggests biaxial flexural strength of 100 MPa acceptable for dental ceramics. However, it seems most appropriate to use metal-ceramic restorations with fracture toughness between 400 and 600 MPa as reference point.[2]

Biaxial flexural strength values were significantly affected depending on the framework and veneering ceramics. Group B/FC was the most resistant to chipping and groups with metal framework (B/FC, B/FF, N/FC and N/FF) were more resistant compared to those of all-ceramic frameworks (D/FC, Z/AL). The favourable results for the metals could be explained on the grounds that bonding between metal-to-ceramic was more durable than in ceramic-to-ceramic due to the oxide layer. Correspondingly, the base alloy having the highest oxidation potential may explain the highest values of toughness for chipping in this group. Other inherent properties such as thermal conductivity, thermal expansion coefficient or wettability of the ceramic could have also influenced the results.

Although the presence of saliva has been simulated using artificial saliva in thermocycling, the lack of occlusal forces during aging process could be considered as the limitation of this study. Thus, incidence of clinical failures after good documentation of the occlusal adjustments is of importance at this stage to verify the findings of this study. Also, new monolithic all-ceramic systems should be evaluated clinically whether their polishing capacity produces less wear in opposing teeth.[31]

Conclusions

From this study, the following could be concluded:

1- Surface roughness of veneering ceramics was the highest after grinding with fine grit flame shaped diamond bur (46 µm) and the lowest after polishing with silicone diamond reinforced disc shaped polishers (25 µm), and glazing.

2- Feldspathic ceramic with fluorapatite presented better polishing results than conventional feldspathic ceramic.

3- Grinding, polishing and glazing did not affect the fracture toughness indicating that chair side surface polishing procedures could restore the surface roughness and mechanical strength to the level of glazing.

4- Ceramic fused to metal groups, and specifically with base alloy, was mechanically more resistant than lithium disilicate or zirconium dioxide framework-veneer assemblies.

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Conflict of interest

The authors did not have any commercial interest in any of the materials used in this study.

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Captions to tables and legends:

Tables:

Table 1. Framework and veneering materials, manufacturers and abbreviations of groups.

Table 2. Surface Roughness (Ra) (µm) of veneering materials after grinding, polishing or glazing. See Table 1 for group abbreviations.

Table 3. Fracture toughness (MPa) of framework-veneering ceramic combinations at chipping and total fracture. See Table 1 for group abbreviations.

Figures:

Fig. 1 "Piston-on-three ball" biaxial flexural strength test where specimens were placed with the framework facing the piston.

Fig. 2 Representative stress-strain graphic of metal-ceramic assembly where the first peak was considered as "chipping" (373 N) in the veneer ceramic.

Fig. 3 Boxplot for fracture toughness of specimens regarding the surface treatment factor where highest values were obtained for the polished group.

Fig. 4 Boxplot for fracture toughness of specimens regarding the veneering material where metal-ceramic assemblies showed higher values than all-ceramic groups.

Fig. 5 Boxplot for fracture toughness of specimens regarding the framework material where metals showed higher values than all-ceramic groups.

Tables:

Experimental Groups	Framework material	Veneer material
D/FC	Lithium disilicate (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein)	Conventional feldspathic ceramic (IPS e.max Ceram, Ivoclar Vivadent)
Z/AL	Zirconium dioxide (Lava, 3M ESPE, Seefeld, Germany)	Feldspathic ceramic with high alumina (Lava Ceram, 3M ESPE)
N/FC	Noble alloy (Cerapall 6, Metalor, Attleboro, USA)	Conventional feldspathic ceramic (IPS InLine, Ivoclar Vivadent)
N/FF	Noble alloy (Cerapall 6, Metalor)	Feldspathic ceramic with fluorapatite (IPS d.Sign, Ivoclar Vivadent)
B/FC	Base alloy (Tilite, Talladium España, Lleida, Spain)	Conventional feldspathic ceramic (IPS InLine, Ivoclar Vivadent)
B/FF	Base alloy (Tilite,Talladium España)	Feldspathic ceramic with fluorapatite (IPS d.Sign, Ivoclar Vivadent)

Table 1. Framework and veneering materials, manufacturers and abbreviations of groups.

Experimental Groups	n	Ground	Polished	Glazed
Surface Roughness (Ra) (µm)		**Mean (SD)***	**Mean (SD)**	**Mean (SD)**
D/FC	15	3.575±0.694a	1.735±0.521	1.819±0.297
Z/AL	15	3.295±0.647a	1.629±0.810	1.913±0.531
N/FC	15	3.773±0.938a	2.597±2.133	2.076±0.437
N/FF	15	3.207±0.325b	0.852±0.183	1.269±0.492
B/FC	15	3.701±1.07a	1.759±0.901	1.961±0.532
B/FF	15	3.511±0.662b	1.605±0.489	1.380±0.303

Table 2. Surface Roughness (Ra) (µm) of veneering materials after grinding, polishing or glazing. See Table 1 for group abbreviations.

(*) Different letters indicate statistically differences between experimental groups (p≤0,05).

Experimental Groups	n	Chipping	Total fracture
Fracture toughness (MPa)		Mean (SD) *	Mean (SD) *
D/FC	15	13.64±6.74a	13.9±6.60 a
Z/AL	15	27.18±3.46a,c	37.50±3.12 a,b
N/FC	15	24.27±1.04a,c	75.65±4.16 c
N/FF	15	24.35±1.04a,c	49.86±3.79 b,c
B/FC	15	69.07±6.07b	69.07±6.07 b,c
B/FF	15	48.72±5.37b,c	62.19±6.63 b,c

Table 3. Fracture toughness (MPa) of framework-veneering ceramic combinations at chipping and total fracture. See Table 1 for group abbreviations.

(*) Different letters indicate statistically differences between experimental groups (p≤0,05).

Figures:

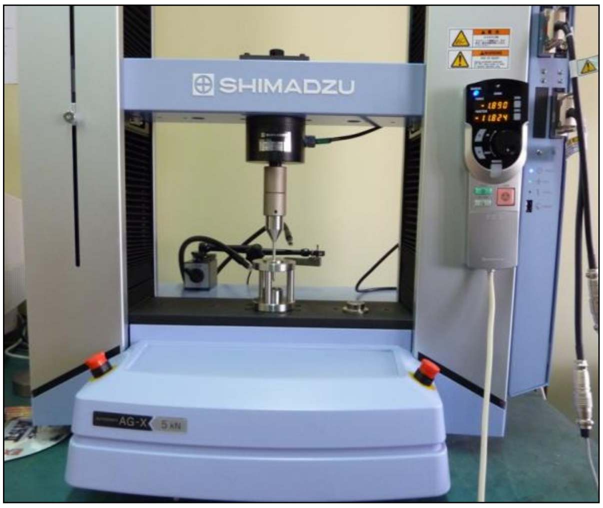

Fig. 1 “Piston-on-three ball” biaxial flexural strength test where specimens were placed with the framework facing the piston.

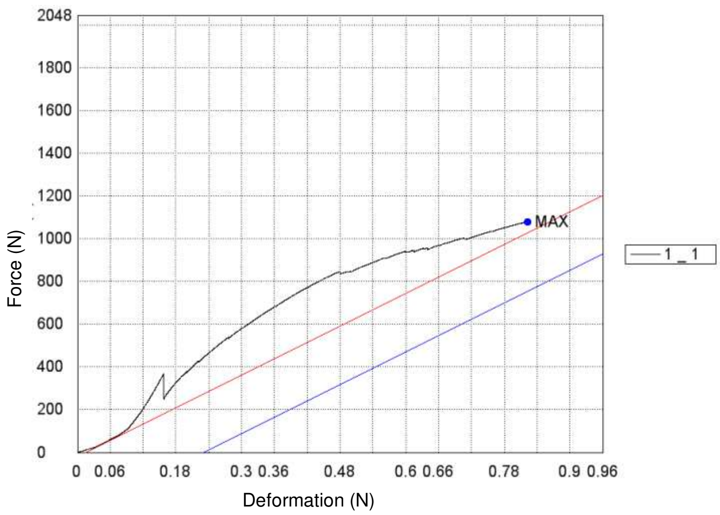

Fig. 2 Representative stress-strain graphic of metal-ceramic assembly where the first peak was considered as “chipping” (373 N) in the veneer ceramic.

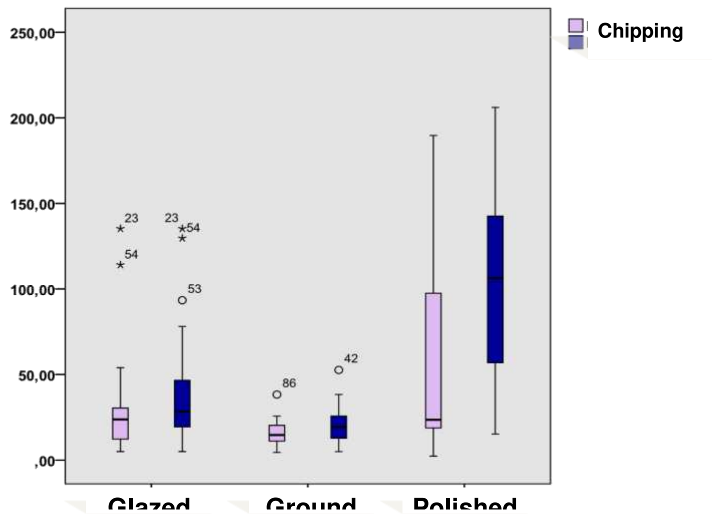

Fig. 3 Boxplot for fracture toughness of specimens regarding the surface treatment factor where highest values were obtained for the polished group.

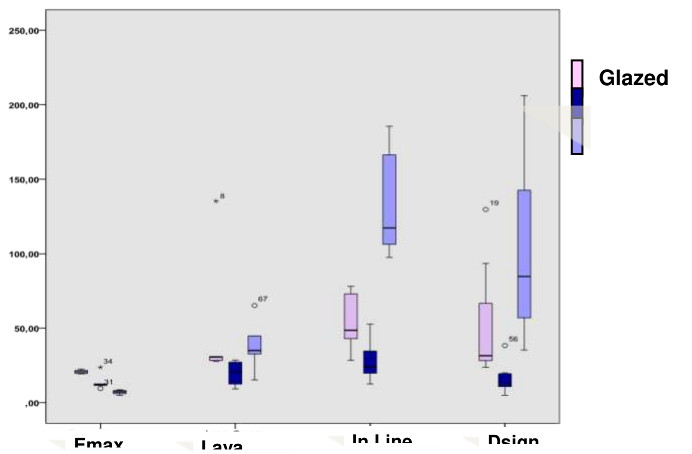

Fig. 4 Boxplot for fracture toughness of specimens regarding the veneering material where metal-ceramic assemblies showed higher values than all-ceramic groups.

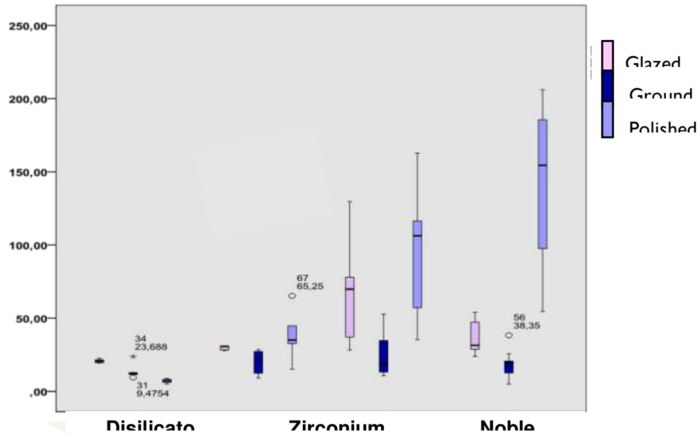

Fig. 5 Boxplot for fracture toughness of specimens regarding the framework material where metals showed higher values than all-ceramic groups.